Brookhaven Magnet Division - Nuclear Physics Program Support Activities

Spin Program support

E-Cooling R&D

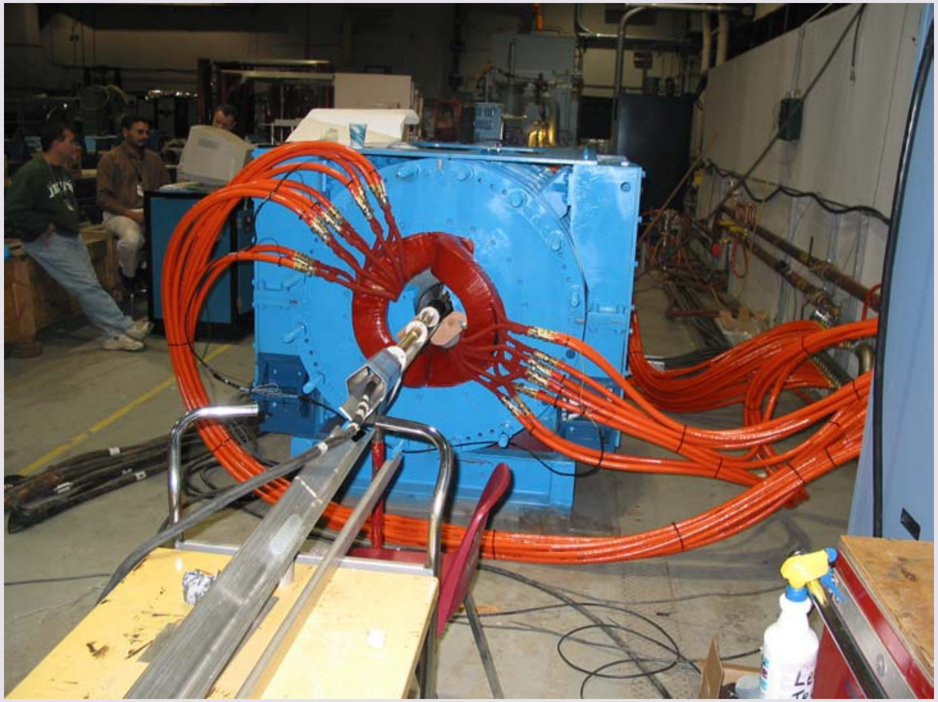
RIA

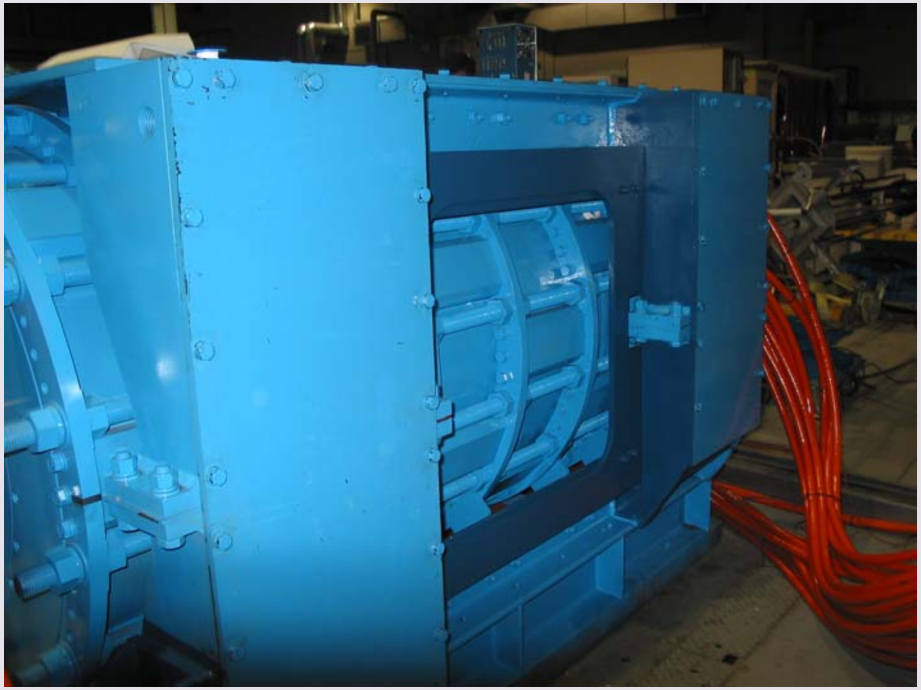
RHIC Operations Support

Funding

AGS Warm Siberian Snake

- AGS Warm Snake
  - Magnetic element designed and built in Japan by RIKEN
  - Shipped to BNL for high power testing: field shape, temperature rise





AGS Warm Siberian Snake

- Measurements included operating temperature rise v's water flow, field quality, field integral

AGS Cold Siberian Snake

- AGS Cold Snake
  - Replace the existing 5% partial snake with a more powerful 30% one. Polarisation 45% -> 70%
  - Issues

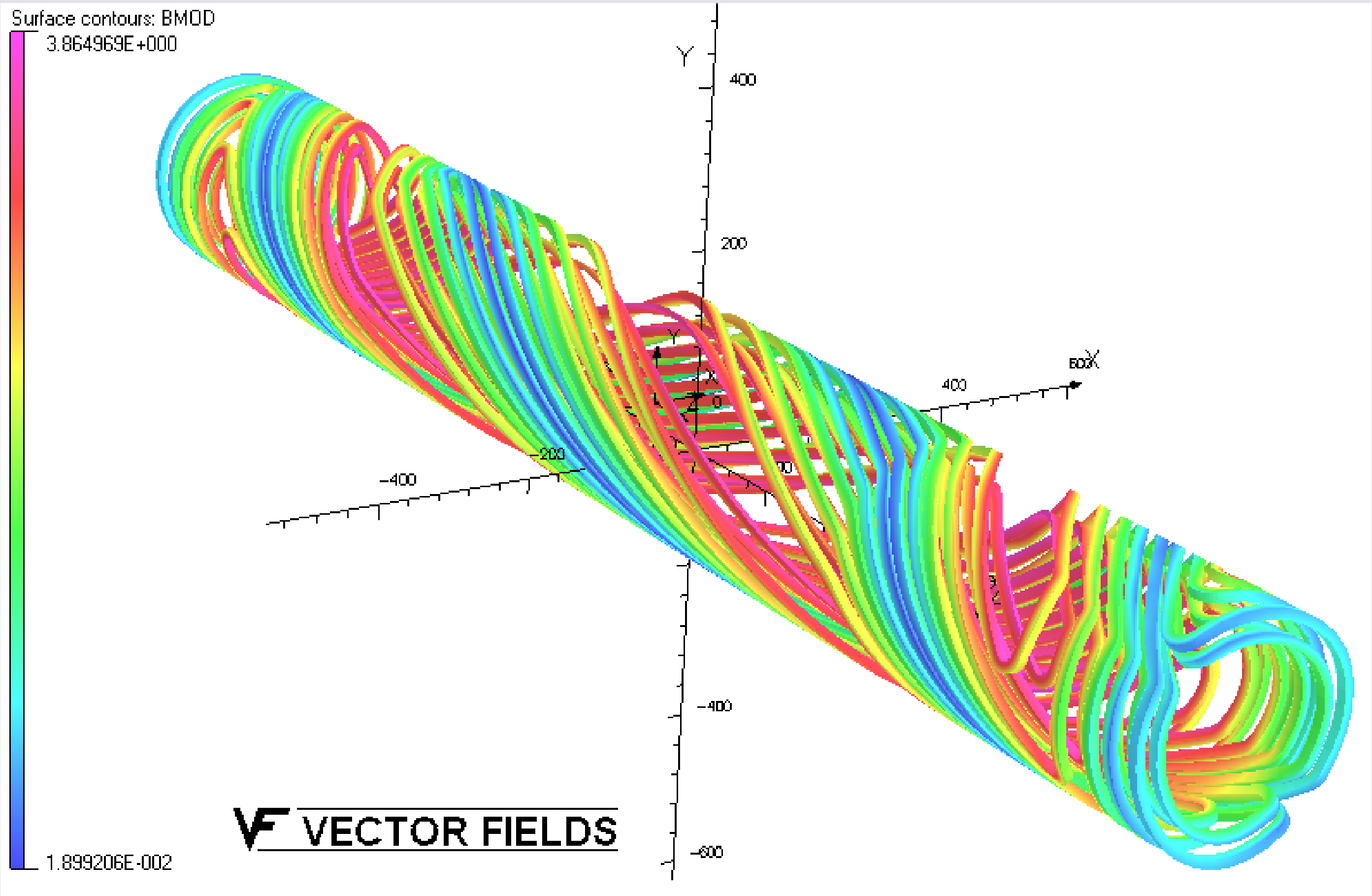
    Complex geometry (variable pitch helix)

    Large aperture, high field (20cm, 3T)

    No cryogenic infrastructure
      - Cooldown -helium back-up from remote dewar
      - Cooling from cryo-coolers for DC operation, 2W heat load max

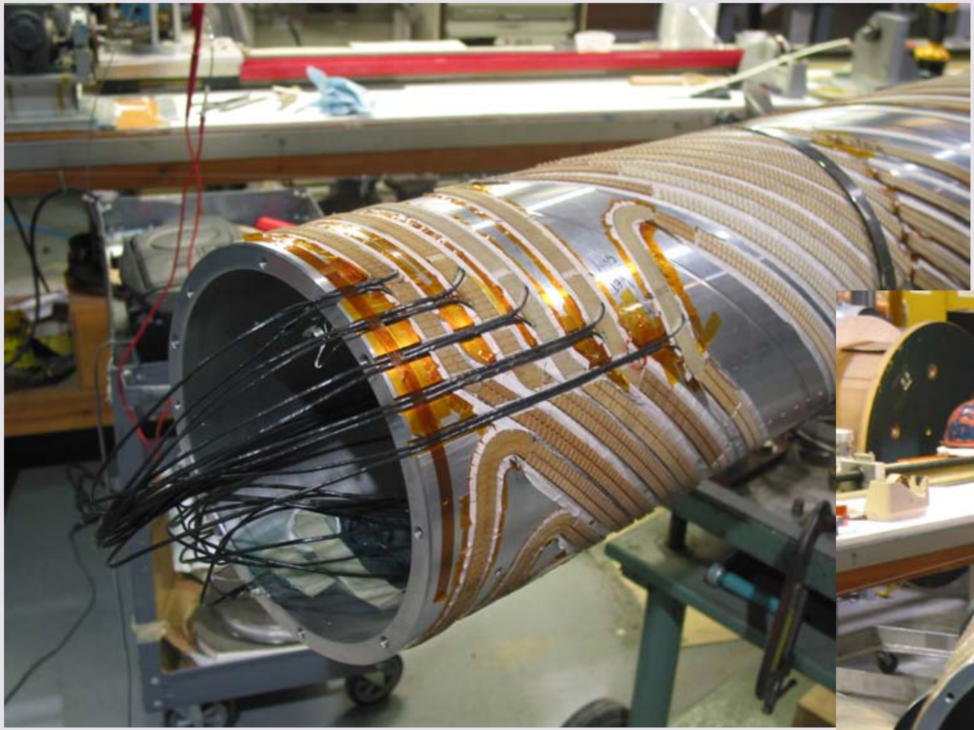
    AGS beam loss induced quenching
      - energy removal

AGS Snake - Coil Geometry



Superconducting
Magnet Division

AGS Snake Status



Inner and outer coils

Cold Snake Central Region: Warm Measurements

Superconducting
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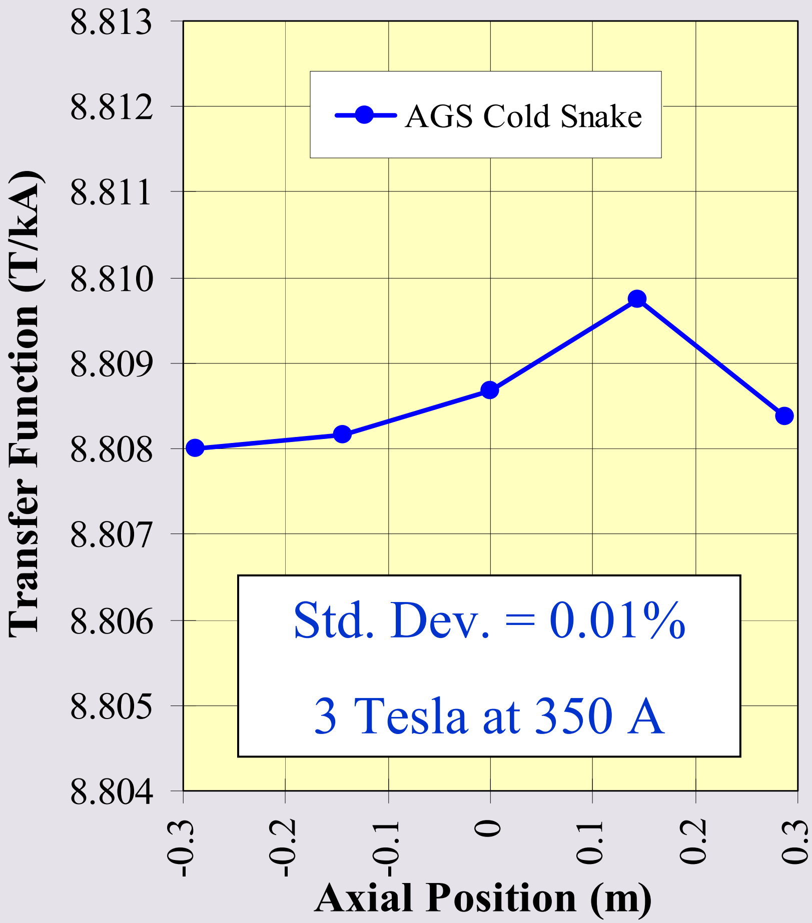
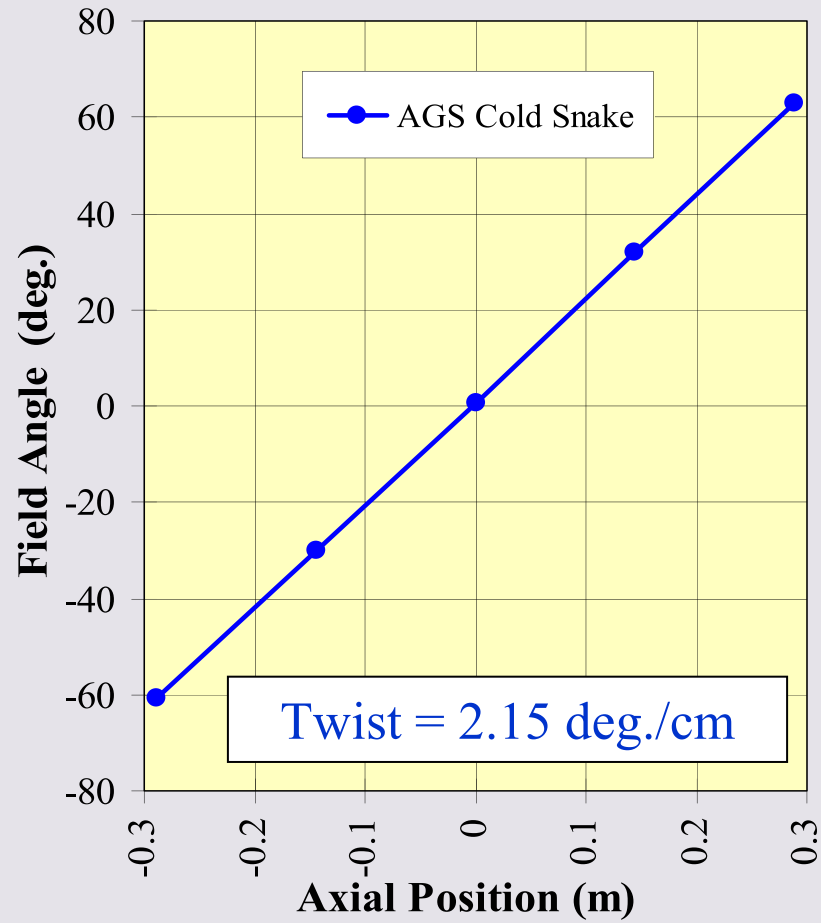
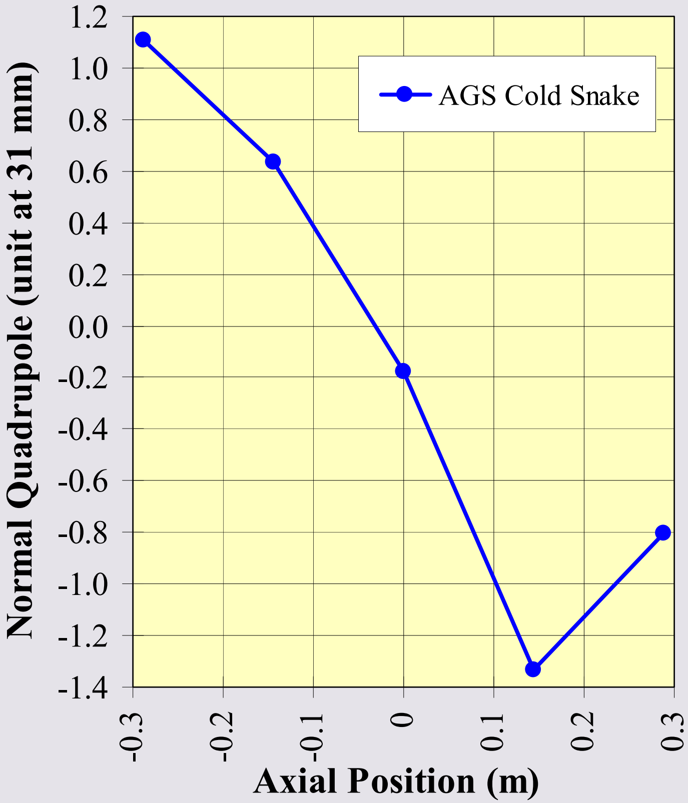
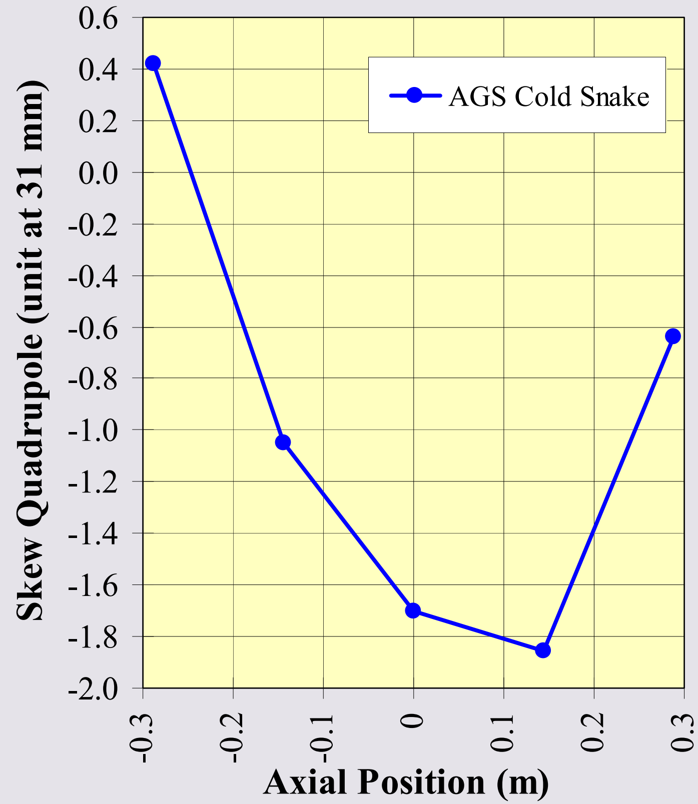


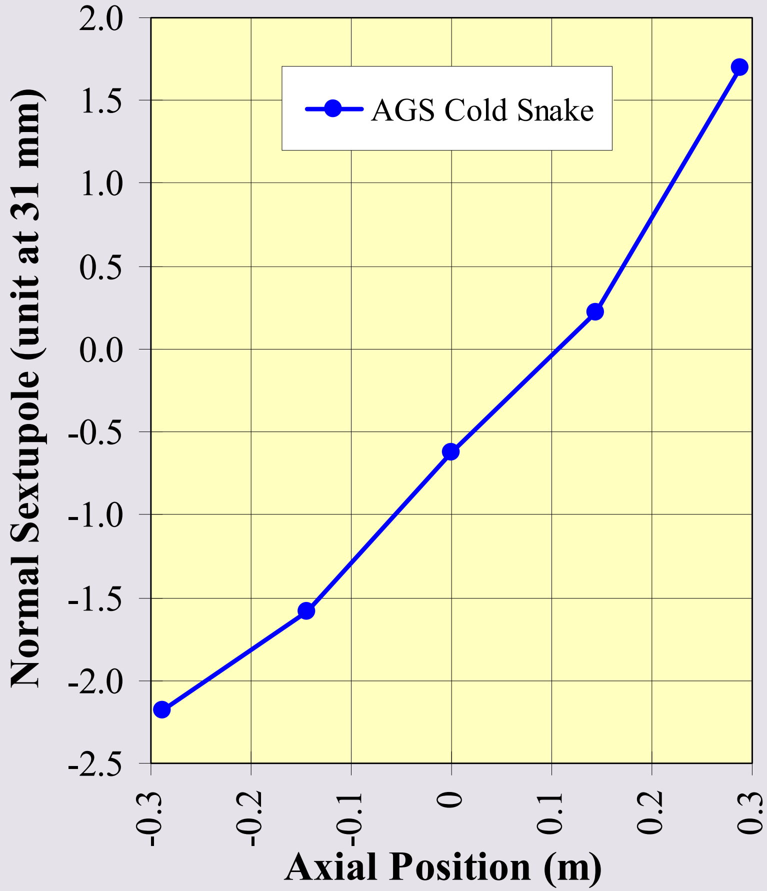


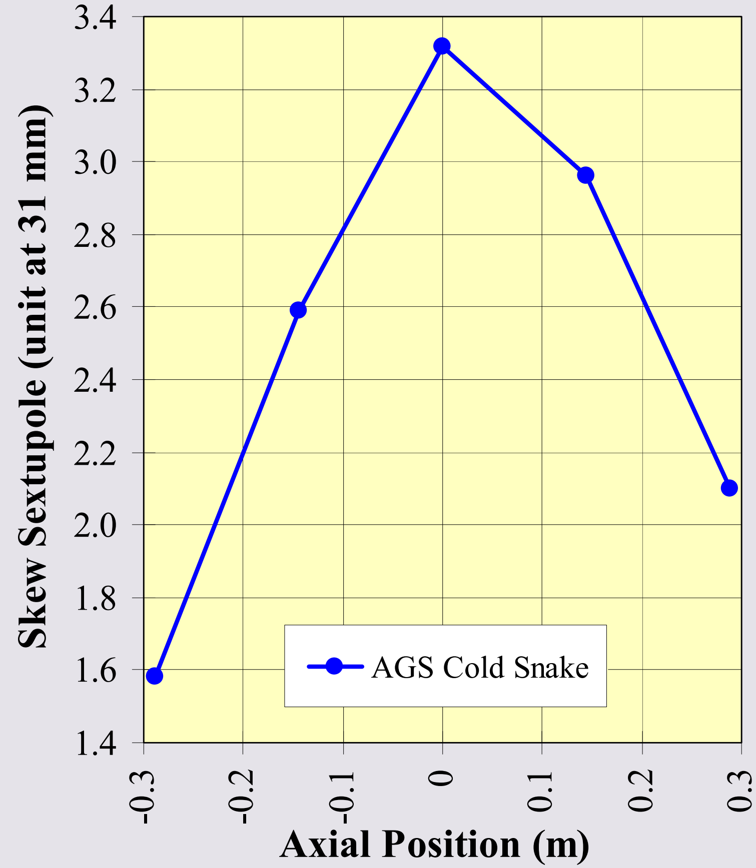
Cold Snake Central Region: Warm Measurements





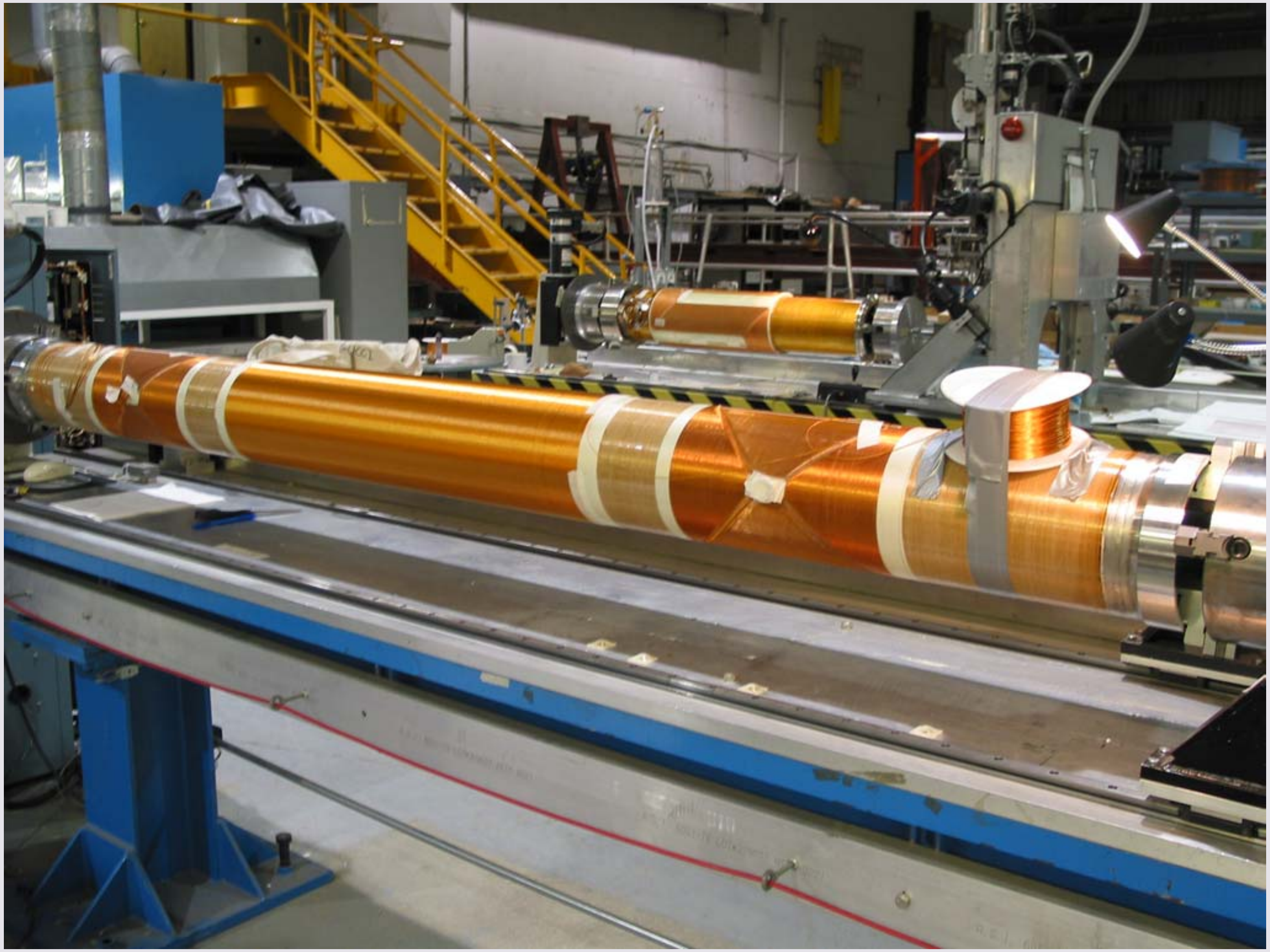
Cold Snake Central Region: Warm Measurements





Superconducting
Magnet Division

AGS Snake Status

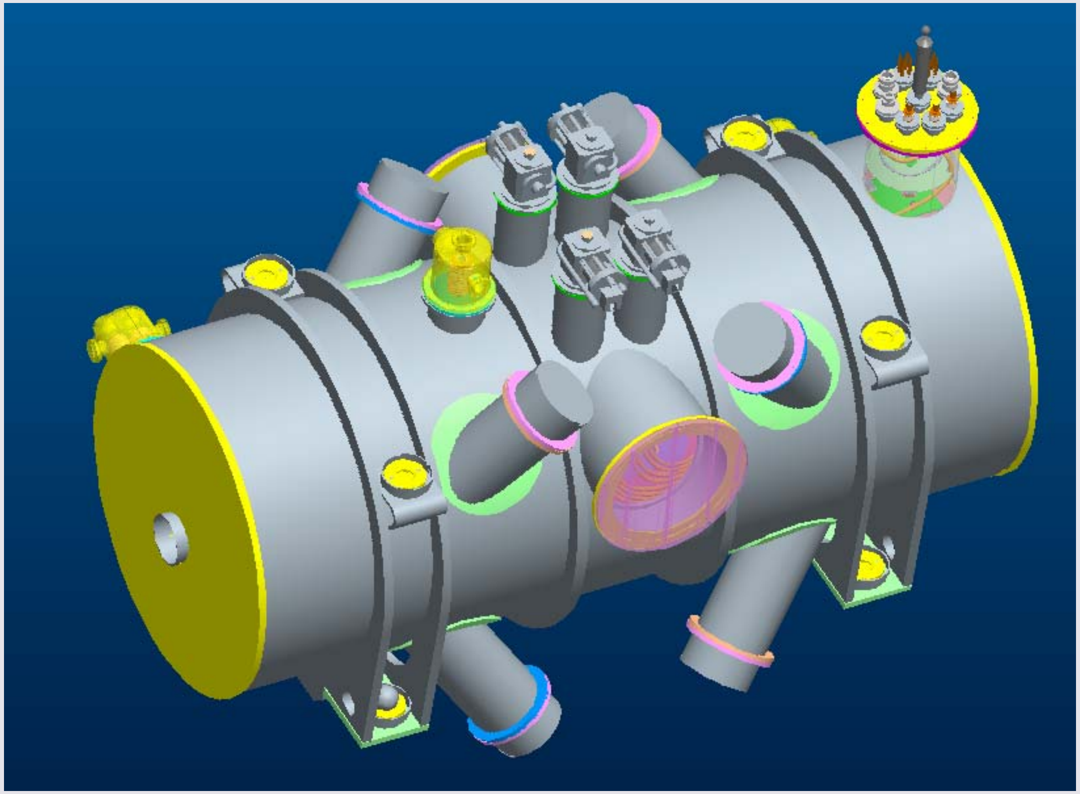


Bore tube wound corrections elements: H&V dipoles + solenoid

AGS Snake Status

Preparing the cold mass for vertical cold testing, estimate July 12th to start the first cold tests

AGS Snake Status



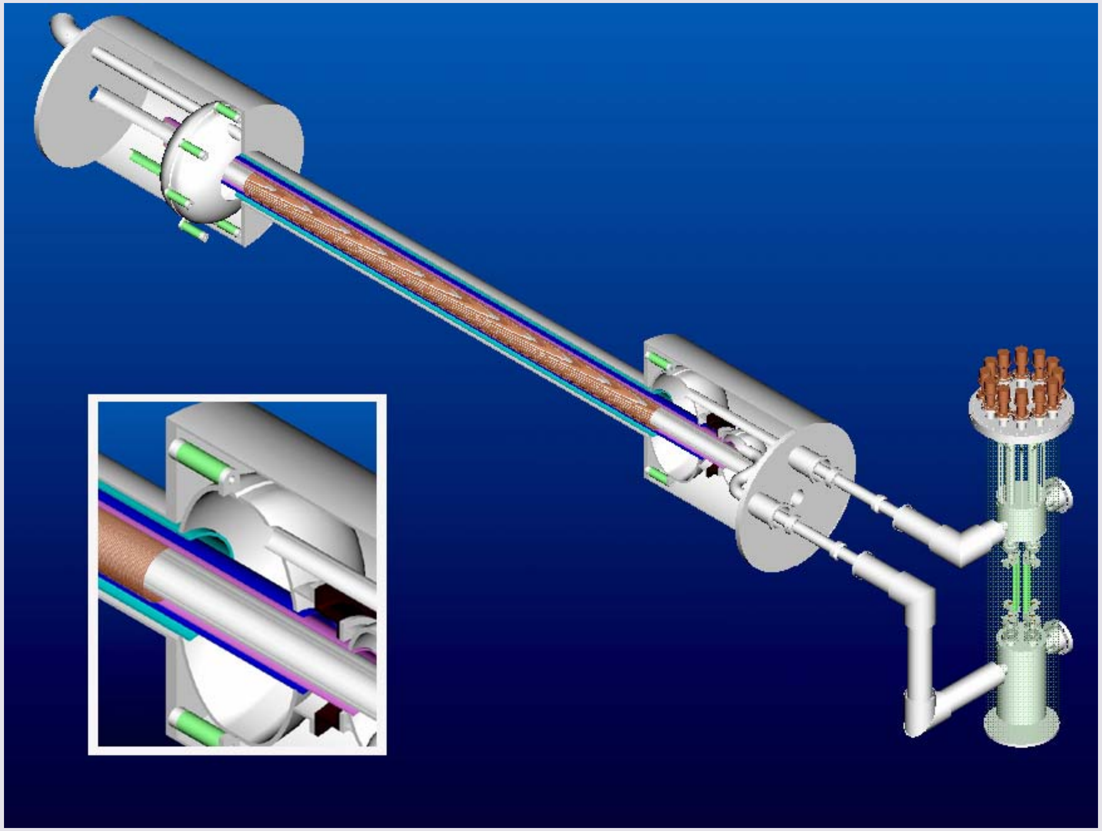
Scheduled for end of construction - ready for final cold testing - on 9/28/04. This schedule has no contingency which given the complexity of the device is probably somewhat optimistic. A complete series of tests are planned since this is a stand alone device. We intend to deliver the magnet to CAD in early December

RHIC II e-Cooling R&D: Solenoid development

Solenoid Requirements

- 2 Tesla axial field (possibility of a 5T requirement)
- Up to 30-meter total length (in two or more sections)
- 100 mm coil ID (gives approx. 89 mm cold bore diameter; warm bore needed?)
- $B_t/B_{axial} < 10^{-5}$
  - on-axis $\Rightarrow$ straightness
  - How about off-axis? At least ~5 mm radius zone is needed just to make measurements.

E-Cooling Conceptual design



- Working on the end configuration which would include short (phase advance) quadrupoles

Dipole Correction Coils

- $B_\perp / B_z \sim 10^{-5}$ implies a straightness of 10 μm over 1 meter length. This may not be achieved with mechanical alignment alone.
- Winding imperfections are also likely to produce transverse fields on-axis.
- Goal is to achieve as close to 1×10^{-5} as possible with construction tolerances and mechanical adjustment (expect ~ a few × 10^{-4})
- Correct the remaining errors with an array of ~ 150 mm long, printed circuit dipole correctors.
- **Two sets of correctors *per axis* are required.**

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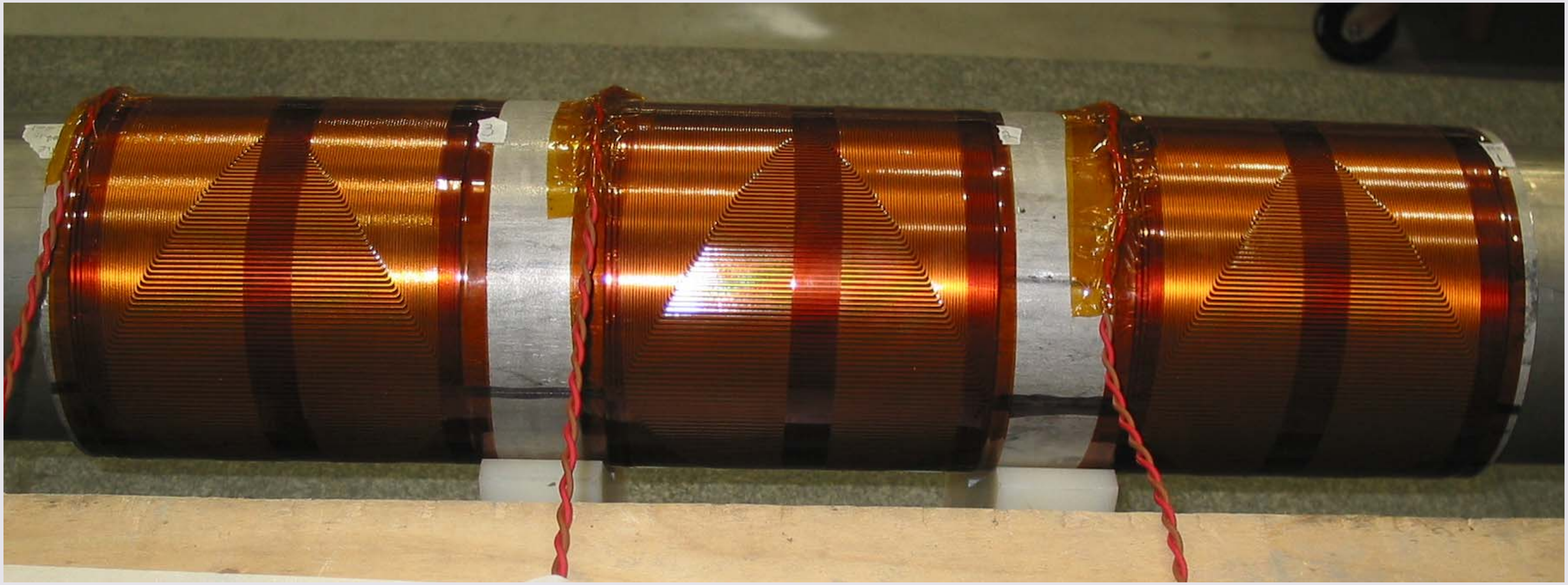
Printed Circuit Dipole Correctors

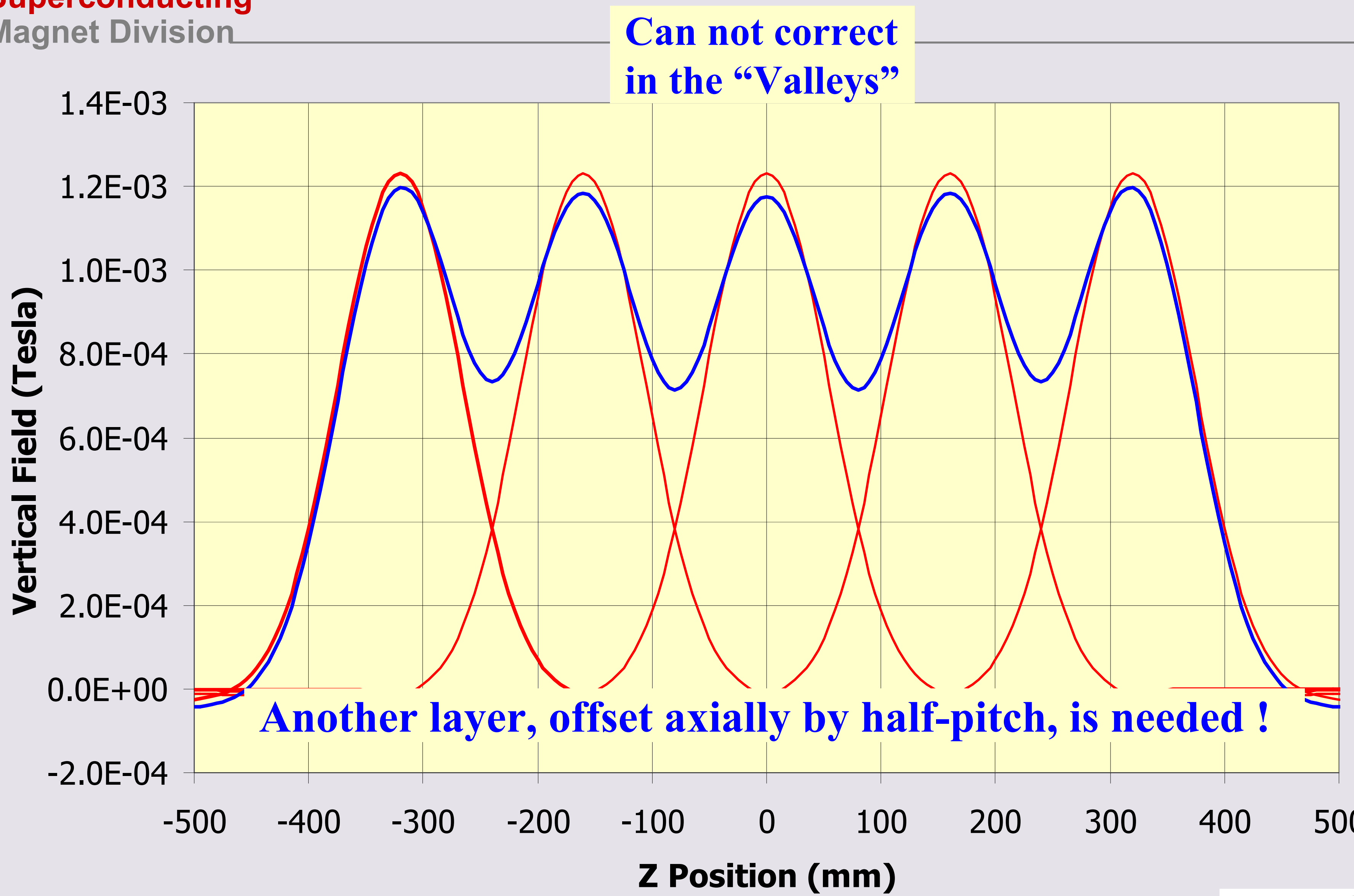


2 Layers of 4 oz Copper patterns; 159 mm ID, 150 mm long

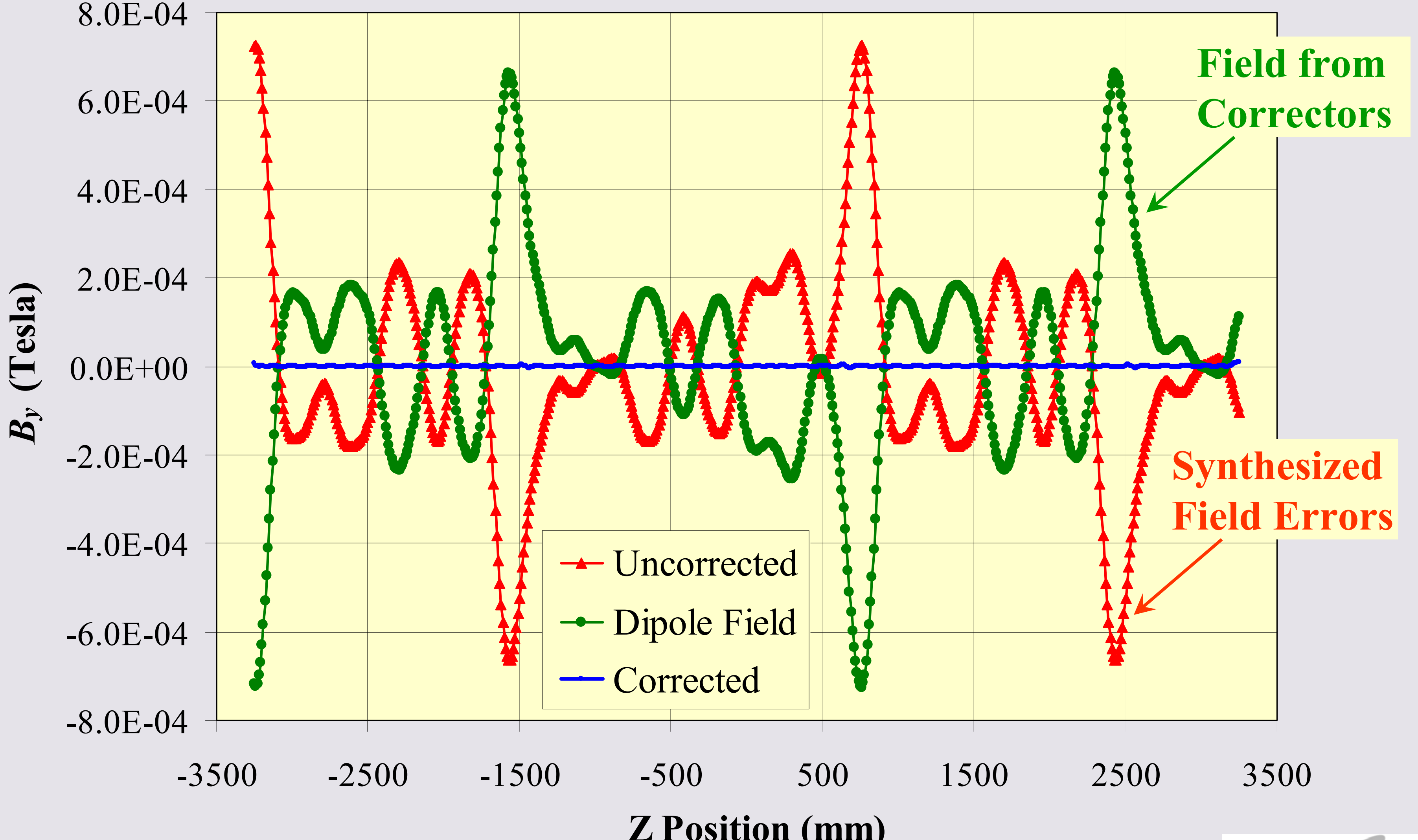
1.25 x 10–3 Tesla central field at 2 A; DB/B ~ 10–3 at 50 mm

Mounted on cryogenic heat shield to minimize dissipated power (approx. 190 W/m expected at full power).

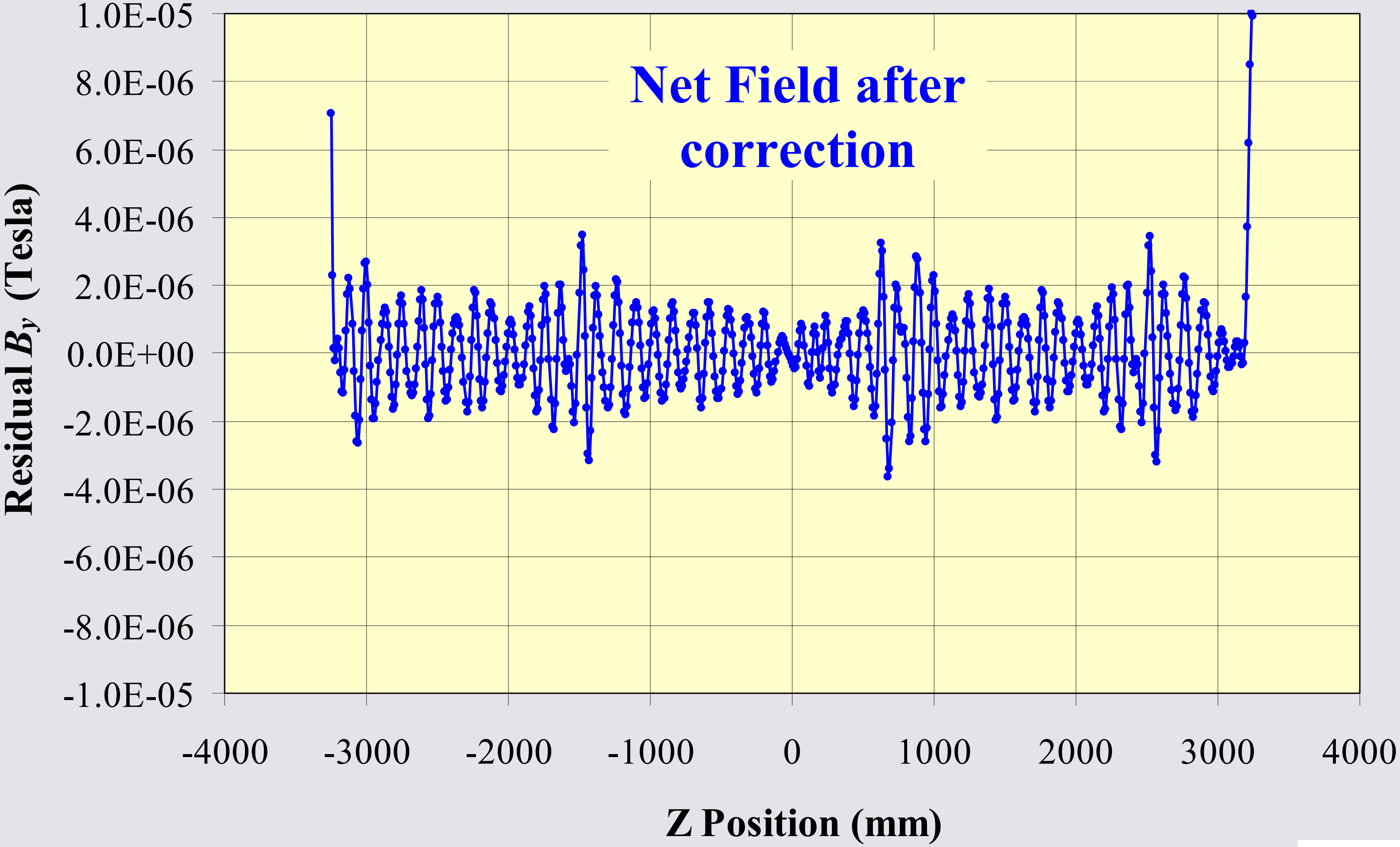
Array of 150 mm long Correctors, 160 mm apart



Simulation to Check Correction Algorithm



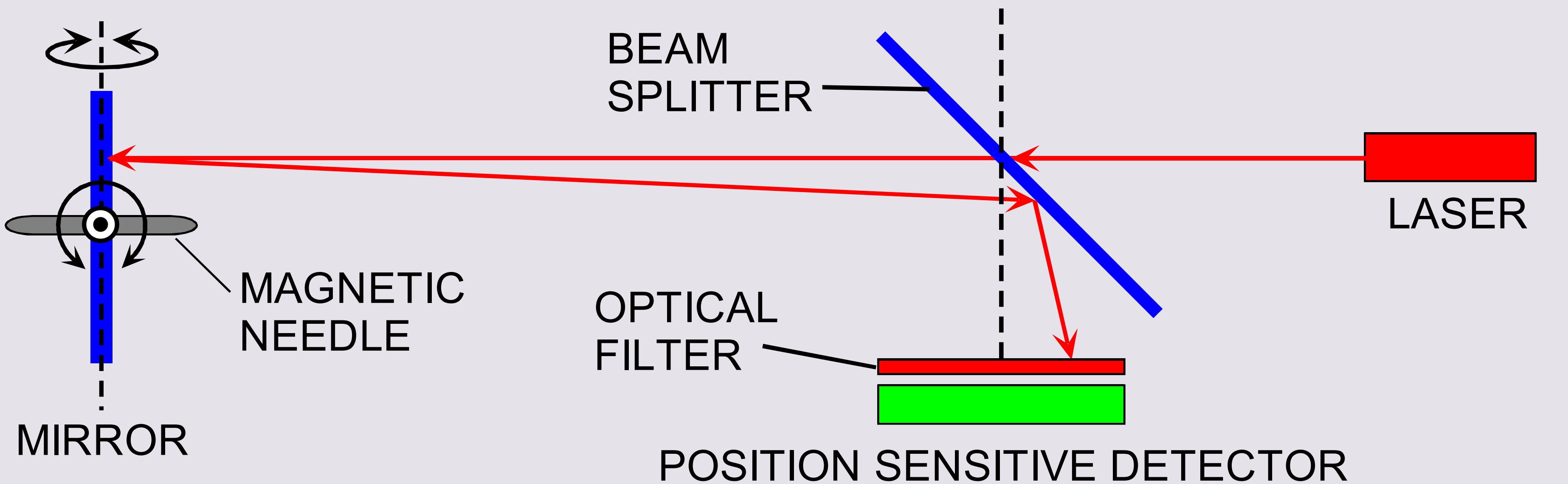
Simulation Results



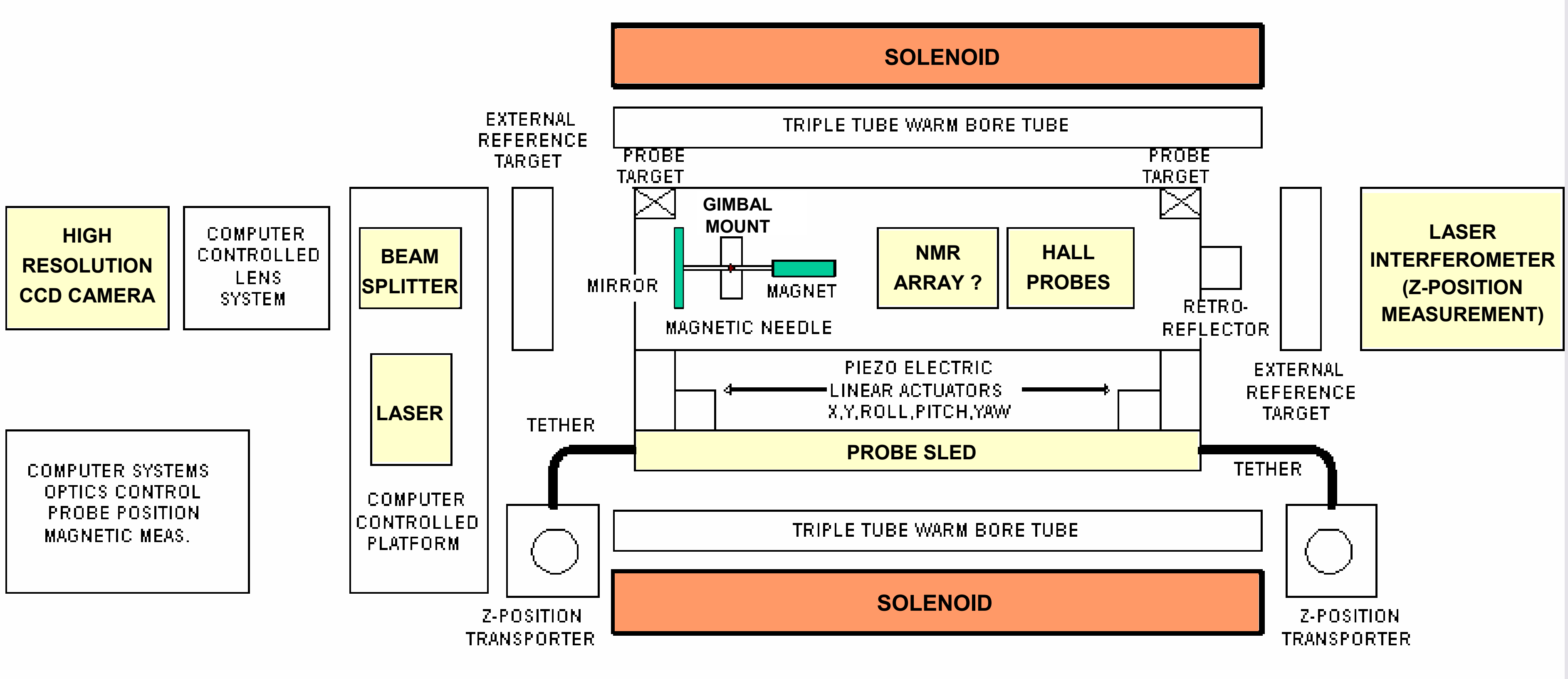
e-Cooler Solenoid Measurement System

3-D Hall probe system (expected resolution of ~10-3 radian)

Magnetic needle and mirror system (expected resolution of ~10-5 radian; used at BINP, IUCF, Fermilab)



Measurement System Schematic



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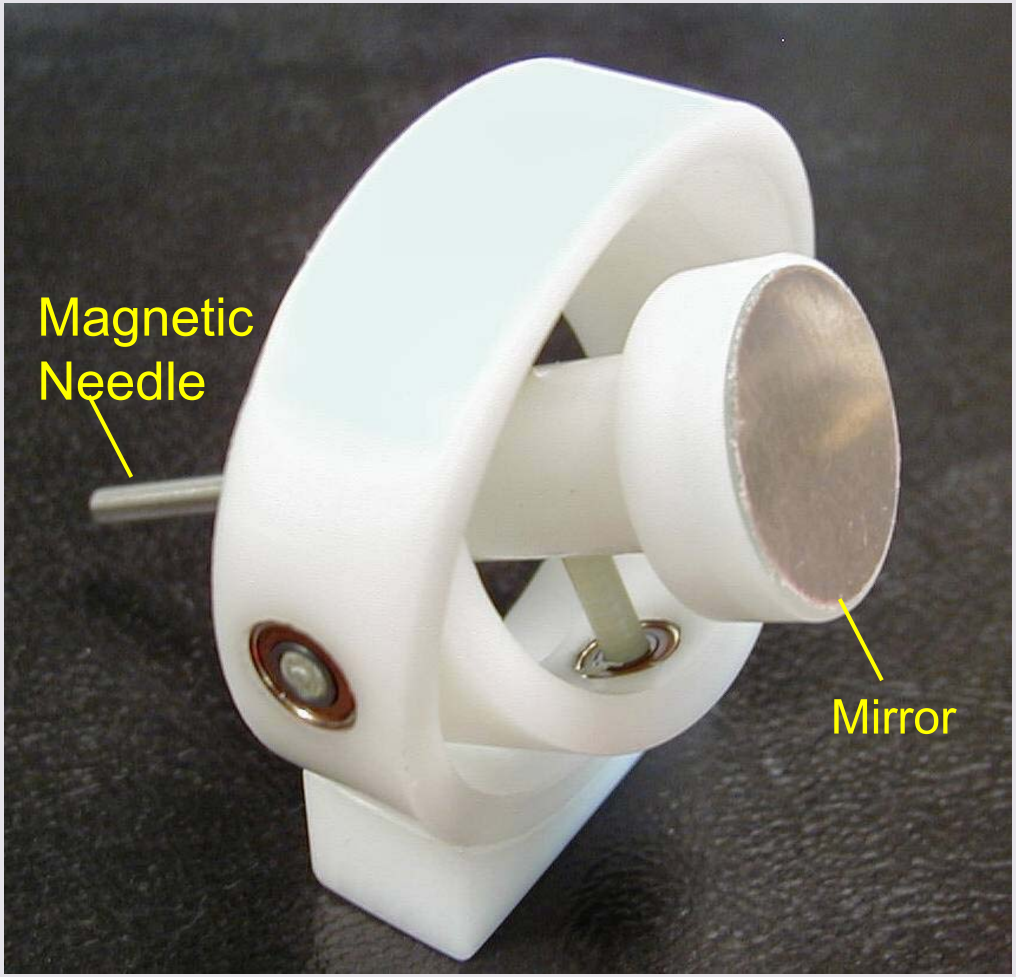
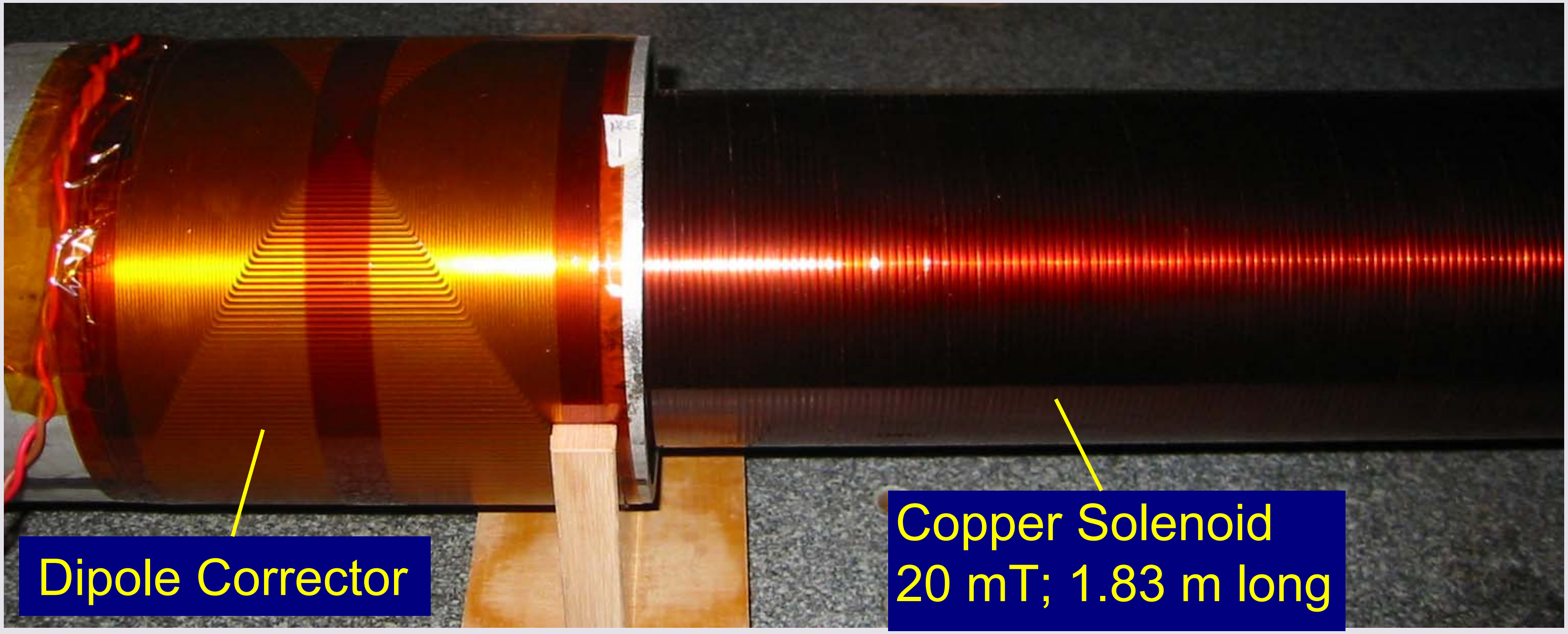
Gimbal mount for magnetic needle and mirror



Setup for testing the measurement system



By exciting the dipole correctors at a known strength, the deflection of laser spot can be compared with the expected change in the solenoidal field direction.

The complete measurement system is currently under development.

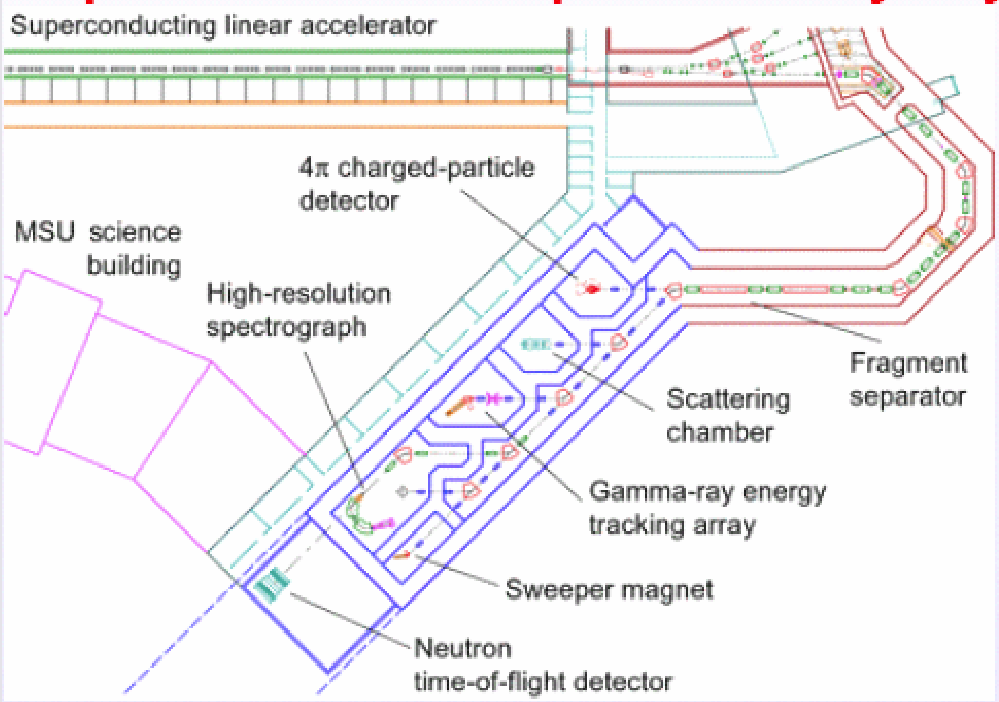
5T Solenoid

Comparison of various solenoid prototype designs for electron cooling

	Quantity	2 T/ 3 m MRI wire	5 T/3 m 18-strand cable	5 T/3 m 16-strand cable
Geometric data	Coil ID	100.0 mm (3.937 in.)	100.0 mm (3.937 in.)	100.0 mm (3.937 in.)
	Coil OD	114.9 mm (4.525 in.)	123.6 mm (4.865 in.)	123.6 mm (4.865 in.)
	Coil length	~ 3 m (~118 in.)	~ 3 m (~118 in.)	~ 3 m (~118 in.)
	Conductor type	Monolithic	18 strands of LHC outer 0.825 mm dia. wire	16 strands of LHC outer 0.825 mm dia. wire
	Bare superconductor	2.362 mm x 1.575 mm (0.093 in. x 0.062 in.)	7.425 mm x 1.650 mm (0.292 in. x 0.065 in.)	6.600 mm x 1.650 mm (0.260 in. x 0.065 in.)
	Cu:SC ratio	6.88	1.9	1.9
	No. of turns per layer	1169	393	441
	No. of layers	4 (for 2 T operation)	6 (for 5 T operation)	6 (for 5 T operation)
	Total no. of turns	4676	2358	2646
Electrical data	Operating current (I_op)	1022 A at 2 T	5070 A at 5 T	4515 A at 5 T
	Short sample limit (I_max)	1500 A (2.94 T) @ 4.22 K	6479 A (6.39 T) @ 4.22 K	5766 A (6.39 T) @ 4.22 K
	J_Cu (quench at I_max)	462 A/mm²	1028 A/mm²	1028 A/mm²
	Inductance	78.1 mH (3 m length)	20.9 mH (3 m length)	26.4 mH (3 m length)
	Stored energy at I_op	40.8 kJ at 2 T (3 m)	269 kJ at 5 T (3 m)	269 kJ at 5 T (3 m)
	Stored energy at I_max	87.9 kJ at 2.94 T (3 m)	439 kJ at 6.39 T (3 m)	439 kJ at 6.39 T (3 m)
	Critical Temp. at I_op	6.2 K at 2 T	5.5 K at 5 T	5.5 K at 5 T
Forces	Total axial force (each end)	13.8 kN (3,100 lbf) @ 2 T	91 kN (20,500 lbf) @ 5 T	91 kN (20,500 lbf) @ 5 T
	Axial force density within a layer (peak; in end regions)	154.3 kN/m (880 lbf/in.) at 2 T (in layer 3)	606 kN/m (3,460 lbf/in.) at 5 T (in layer 4)	606 kN/m (3,460 lbf/in.) at 5 T (in layer 4)
	Radial force density within a layer (peak; in axial center)	222.5 kN/m (1,270 lbf/in.) at 2 T (in layer 1)	973 kN/m (5,560 lbf/in.) at 5 T (in layer 1)	973 kN/m (5,560 lbf/in.) at 5 T (in layer 1)
	Peak Hoop stress in coil	25.3 MPa (3,700 psi)	101 MPa (14,600 psi)	101 MPa (14,600 psi)

RIA R&D

Magnetic elements (quads) in fragment separator region will live in a very hostile environment with a level of radiation and energy deposition never experienced by any magnet system before.



- Beam loses 10-20% of its energy in production target, producing several kW of neutrons.
- Quads are exposed to high radiation level of fast neutrons.

Room temperature, water cooled copper magnets produce lower gradient and/or lower aperture, reducing acceptance and making inefficient use of beam intensity.

Basically, we need *"radiation resistant"* superconducting quads, that can withstand large heat loads. There are many short and long time scale issues!

RIA R&D

- As compared to the conventional Low Temperature Superconductor (LTS), the critical current density (J_c) of High Temperature Superconductor (HTS) falls slowly as a function of temperature.

- The magnet system benefits enormously from the possibility of magnets operating at elevated temperature (20-40 K instead of conventional ~4K).

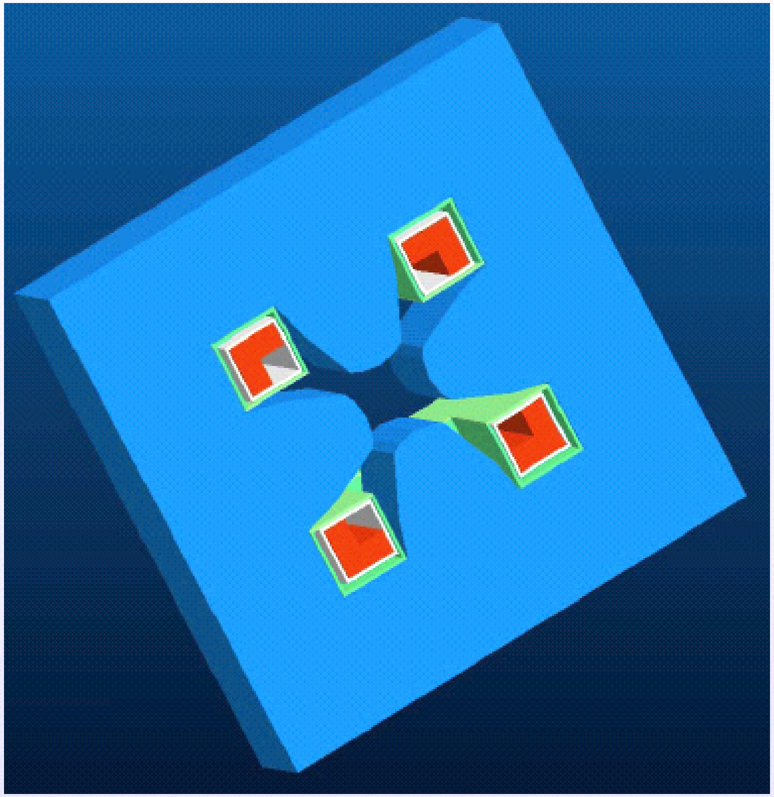
- HTS can tolerate a large local increase in temperature in superconducting coils caused by the decay particles.

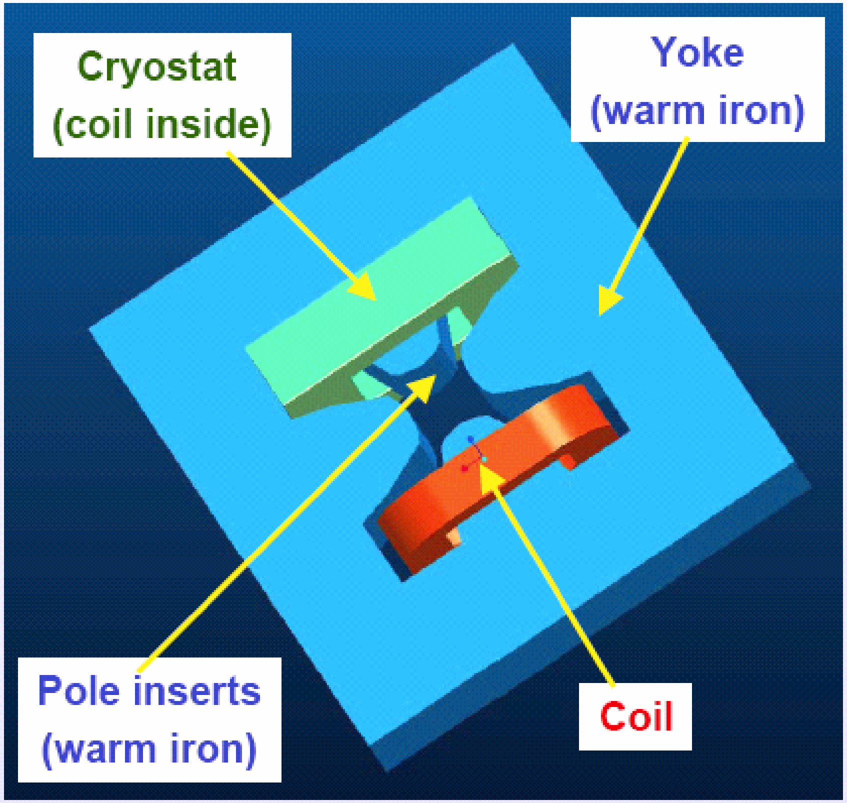
- Moreover, the temperature need not be controlled precisely. The temperature control can be relaxed by over an order of magnitude as compared to that for present superconducting accelerator magnets.

RIA R&D

A simple warm iron super-ferric quad design with two racetrack HTS coils

Note that only a small fraction of mass is cold (see green portion), and also that it is at a large solid angle from the target



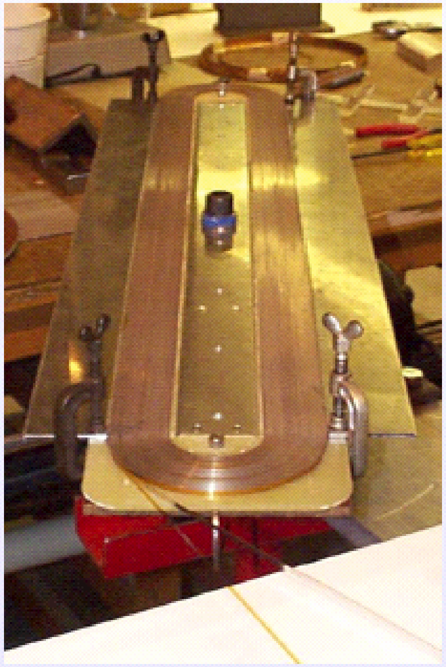


RIA R&D

BNL has successfully tested several HTS R&D magnets and test coils made with BSCCO 2212 and BSCCO 2223 tape. A unique and very pertinent feature of these coils is the successful use of stainless steel as the insulation material between turns. This technique was developed to provide a strong mechanical coil package capable of withstanding the large Lorentz forces in a 25T environment, but will also provide a highly radiation resistant coil.

Two double pancake NMR coils, one with kapton insulation and the other with stainless steel.

S.S. insulation works well with superconductors



HTS Test Coil for an Accelerator Magnet

RIA R&D

Test coils in progress. Since the FY04 funding only arrived in April we will try and complete a test coil comprised on 6 sub units in a magnetic mirror configuration and test in a vertical dewar by the end of the calendar year.

RHIC Magnet Systems Scope

A large superconducting inventory of magnets:

- ~ 300 8cm dipoles
- ~ 400 8cm quadrupole/sextupole/corrector units
- 96 13cm IR quadrupoles
- 24 10cm IR dipoles
- 12 18cm IR dipoles
- 12 siberian snakes/spin rotators (48 helical dipole units)

RHIC Magnet Repair

To date we have experienced failures in:

- A RHIC helical dipole cold mass
  - A great deal of testing time in the magnet division was expended to track down the root cause of this failure. We suspected the quench detection algorithm was incorrect. Tests proved inconclusive, changes to the quench detection were made none the less
- A CQS correction element package
  - A dipole layer
- A trim quadrupole in a CQS unit (in progress)
  - The problem is believed to be the wiring card

NP Program Support

- Cryogenic engineering
- Cryogenic controls software
- Quench protection/magnet power supply system integration and fault diagnosis
- Quench protection system development
- AGS rapid cycling field measurements

Magnet Division Funding

Nuclear Physics	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005
NP program magnet support	$4,786	$4,740	$5,350	$5,874	$6,020
FTE's	25.5	26.5	28.5	29.0	29.0
RIA R&D				$290	$350 (?)
FTE's				2.0	2.5
CAD support non magnet FTE's				6.0	6.0
High Energy Physics					
LHC		$9,707	$4,307	$2,302	$780
Base program		$1,063	$990	$1,000	$1,000
		44.0	30.6	18.8	12
Other					
			$2,600	$3,840	$2,095
			16.3	26.8	15

We assume that the magnet program will remain at this level of effort (~29 FTE's) for the foreseeable future.

This represents ~40% of the Magnet Division's total activity.

Obvious problem in FY05 from HEP

Summary

The RHIC program support requirements are maturing (as is the machine):

Magnetic measurements are becoming more subtle

Magnet technology is becoming more complex

No major production tasks anticipated in the near future. We are moving into a low volume, R&D, environment (spin, e-cooling, e-RHIC).

Possible issues with the helical dipoles. The other RHIC magnets appear to be very reliable.

Planning on a constant level of effort